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Population density of *Tarsius supriatnai* along a forest degradation gradient in Popayato-Paguat landscape (Gorontalo Province, Sulawesi)

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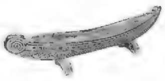
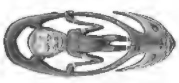
Abstract: Jatna's Tarsier *Tarsius supriatnai* Shekelle, Groves, Maryanto et Mittermeier, 2017 is a species of primitive primates described very recently from the western part of the Gorontalo Province in North Sulawesi (Shekelle *et al.* 2017). The main aim of the present study is to identify correlations between forest degradation and conversion and population densities of Jatna's Tarsier in a typical forest edge to agricultural land transition area in Popayato Paguat landscape and provide ecological data about the species and its spatial distribution. The results show that *Tarsius supriatnai* is not entirely restricted to the secondary forest. As long as small particular remnants of natural vegetation remain in the landscape, tarsiers are found be able to persist, but their population densities are considerably lower. Average population densities on agricultural-agroforest area (1.22 individuals/ha) differ significantly from those within the secondary rainforest (5.37 individuals/ha). Moreover, average population densities at the study plots undergoing forest conversion (1.05 individuals/ha) differ significantly from those unaffected (5.65 individuals/ha) by rainforest degradation (4.07 individuals/ha). Regarding to the IUCN Red List assessment guidelines, we confirm the criterion "VU Vulnerable" for *Tarsius supriatnai* based on the results of the present study.

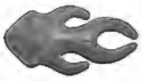
Key words: *Tarsius supriatnai*, population biology, Popayato Paguat landscape, Sulawesi.

Introduction

Deforestation and rainforest degradation rates in Indonesia are still the highest in Southeast Asia and even globally rank among the top three among tropical countries. Deforestation, forest degradation and conversion of natural forests into agricultural land are the main terrestrial threats to many species in the global biodiversity hotspot Wallacea, including its most enigmatic island of Sulawesi – a place of extraordinary endemism in mammals. In Popayato Paguat landscape, a designated Key Biodiversity Area (KBA), the non-governmental organization Burung Indonesia, with support of the NABU and KfW (German Development Bank) aim to improve forest management and maintain landscape connectivity between Nantu Forest Reserve and Panua Protected Area. Our research aims to test the indicator function of an endemic species towards forest disturbances along a gradient of forest use and conversion in this landscape and provide some additional biological data on this elusive and insufficiently studied small primate species. Tarsiers are remarkable, fully insectivorous primates. Originally thought to be only a single species (*Tarsius tarsier* (Erxleben, 1777), also widely known under the synonymized name *Tarsius spectrum* (Pallas, 1778)), tarsiers from Sulawesi and surrounding islands represent a complex comprised of 12 species as is considered today. Especially in recent years tarsier taxonomy has been improved by clarification of the taxonomic status of taxa from the northern arm of Sulawesi Island, including the recent descriptions of *Tarsius spectrumgurskyae* Shekelle, Groves, Maryanto et Mittermeier, 2017 and *Tarsius supriatnai* Shekelle, Groves, Maryanto et Mittermeier, 2017 (Shekelle *et al.* 2017) (Fig. 1). While the taxonomic status of South and South-Central Sulawesi populations is still unclear, with the description of *Tarsius niemitzi*







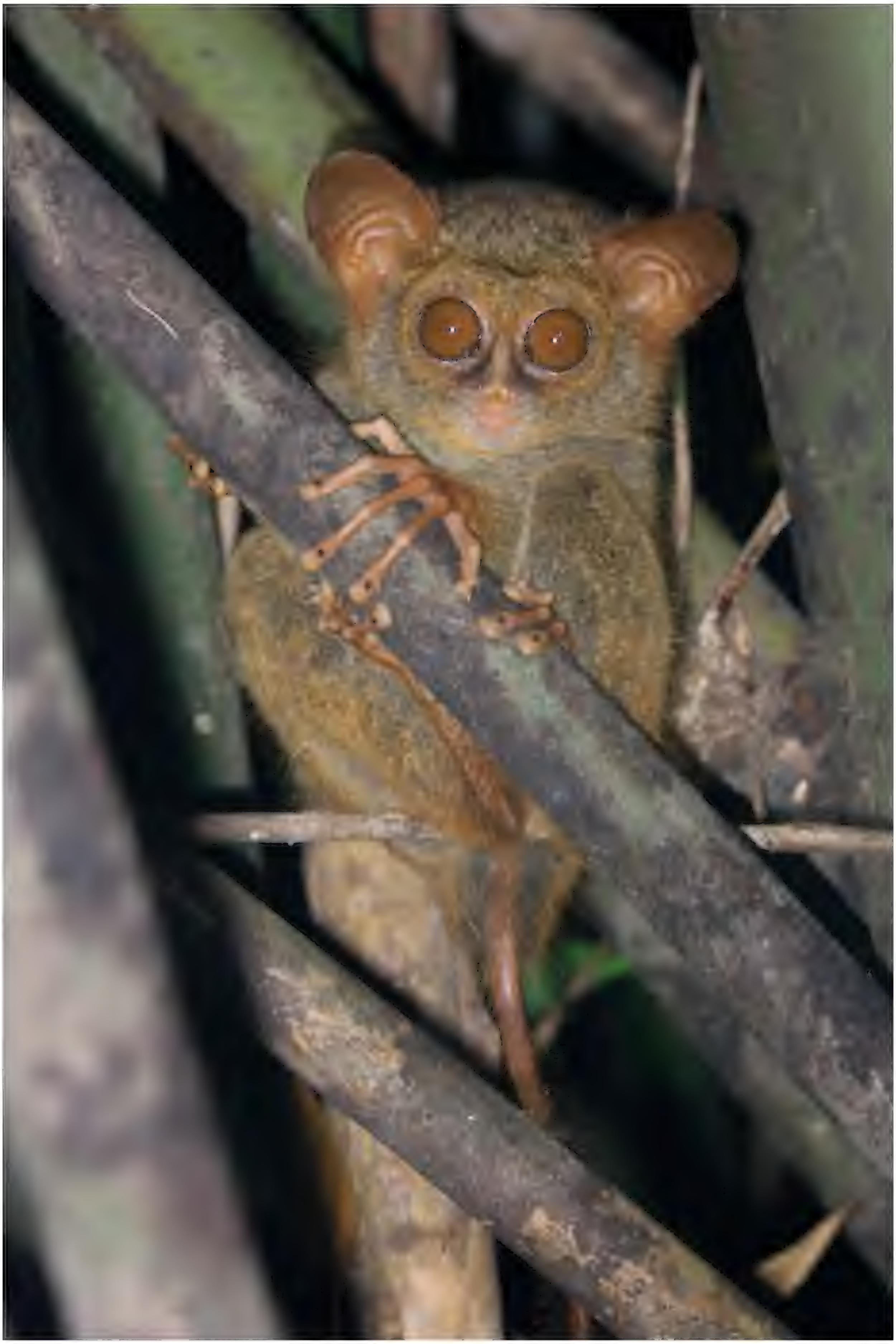


Figure 1. Jatna's Tarsier *Tarsius supriatnai* Shekelle, Groves, Maryanto et Mittermeier 2017, specimen from the plot No 108 (photograph: Tom Kirschey, 17.i.2020).

Shekelle, Groves, Maryanto, Mittermeier, Salim et Springer, 2019 from the Togean Islands in the Gulf of Tomini the unclear situation has been solved for the northern part of Sulawesi and adjacent islands (Shekelle *et al.* 2019). *Tarsius supriatnai* is distributed West of the Gorontalo (geotectonic) fault between the Popalo Bay in the North and Gorontalo City (including Limboto) in the South, whereas populations East of the Gorontalo fault are represented by *Tarsius spectrumgurskyae* (Shekelle *et al.* 2017).

Material and methods

The field research was conducted for a two months period in December 2017 and January 2018 around a small village next to the rainforest edge in the Popayato-Paguat landscape, Gorontalo province, Sulawesi. During this period on a daily basis excursions along a transect between the village and the forest area have been conducted during the maximum activity period of the tarsiers. The forest, agricultural area and different transition stages have been classified in order to verify the habitat suitability for tarsiers. For the study, 29 study plots (all subject to human-induced disturbance), have been arrayed along river bank oriented transects (Fig. 2). Fourteen of these trial plots were set up within a tropical old-secondary lowland rainforest on mineral soil, which served as reference site by providing ideal habitat conditions. Another 15 study plots were delineated on diversely used agricultural land, which has undergone severe forest degradation and conversion. The data collection was conducted by recording the duet vocalizations at dawn and locating the direction of sound. Defined cultivation types, highest reached vegetation layer, density of riparian vegetation, river bank connecting vegetation (closed tree canopy across rivers), forest cover loss since 2001, occurrence of secondary forest fragments, height differences within each study plot and the potential sleeping trees were considered in order to answer the goals of this study.

Investigation area

Popayato Paguat landscape is an area in the West of the Gorontalo Province in the regencies of Pohuwato and Boalemo in the Northern part of the island of Sulawesi. The area has been classified as a Key Biodiversity area (KBA) (Burung Indonesia 2014; Wood *et al.* 2015). The landscape includes the lowlands and southern slopes of the mountain ridge between 48 and 980 m altitude and edges of villages as well as agricultural land. Some authors refer to this landscape as the Polahi-Marissa Forest Complex (Cannon *et al.* 2007). The settlement today known as Makarti Jaya village area (Fig. 3) was established in 1994, when the first families were brought to our study area under the Indonesian transmigration settlement program. The settlement was then known under the name “Unit Pemukiman Transmigrasi (UPT) Marisa V”. Because of the

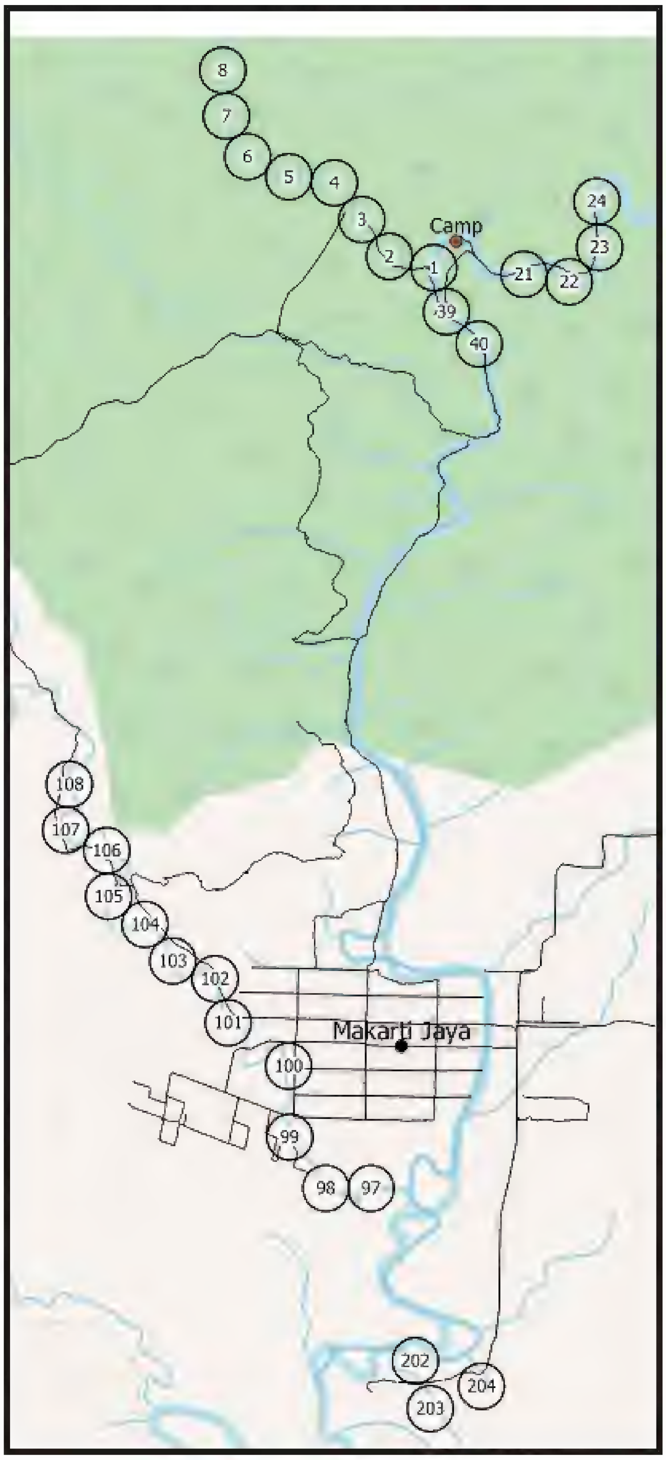


Figure 2. Arrangement of trial plots (Scale 1 : 35 000, QGIS 3.4, OSM Standard).

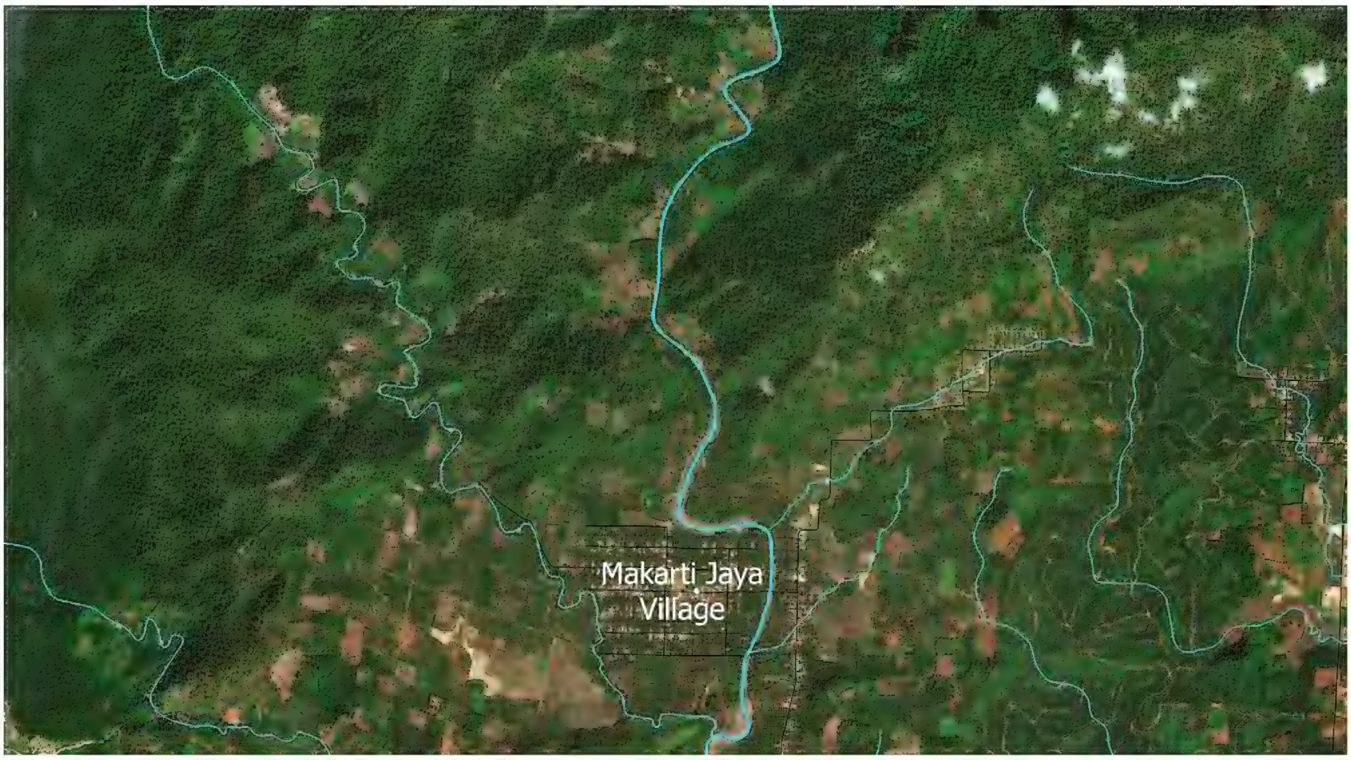


Figure 3. Satellite image showing the forest coverage around the study site in Makarti Jaya village, Sulawesi.

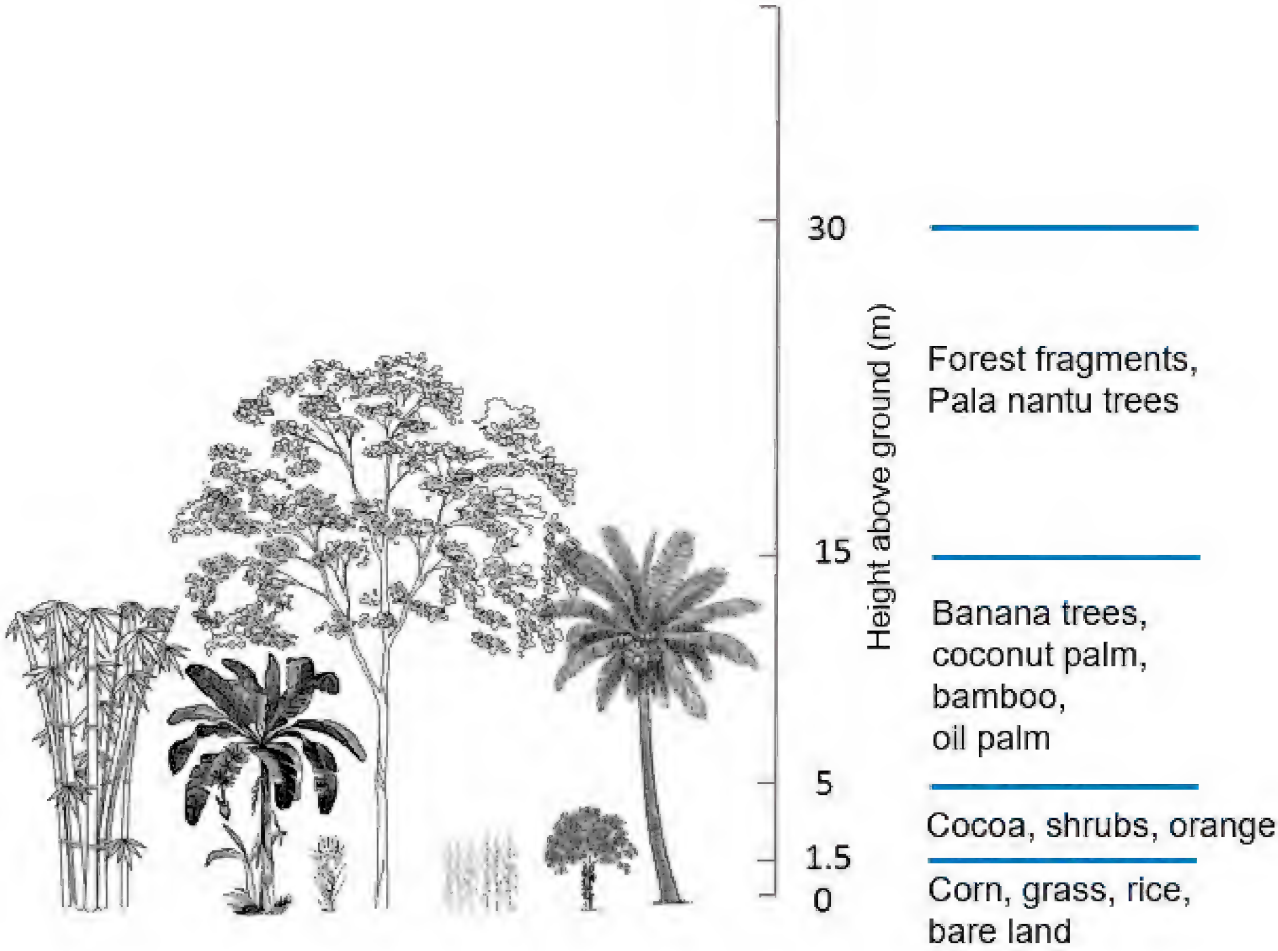

30
15
5
1.5
0
Height above ground (m)
Forest fragments, Pala nantu trees
Banana trees, coconut palm, bamboo, oil palm
Cocoa, shrubs, orange
Corn, grass, rice, bare land

Figure 4. Agricultural crops and agroforestry composition in Makarti Jaya village, Sulawesi, based on a secondary forest stratification model.

compatibility of cocoa trees with soil and climate in this region, their dowry provided by the state were cocoa seedlings to establish a livelihood. Since 2002 the former UPT counts as official village under the name Makarti Jaya (Makarti = work, Jaya = success; Makarti Jaya = success through work). The cultivation of cocoa has proved successful for the villagers. The community today has several cocoa nurseries and most of the livelihood of the village is generated by farming cocoa and corn. The forest itself is classified as production forest ("Hutan Produksi") and comprises of a secondary forest as a result of natural succession after this area was logged out more than three decades ago (Fig. 4). It is a seasonally dry lowland to mid-montane Fagaceae-Myrtaceae forest with *Lithocarpus* spp., *Ficus* spp., and *Calamus* spp. When activities to establish an Ecosystem Restoration Concession (ERC) in the Production Forest block have been started, Makarti Jaya was selected to be a key village in a forest management program by Burung Indonesia and its partners (Kirschey & Schell 2016).

Results

The numbers of tarsiers per trial plot in the reference area were higher than the numbers on the study plots within the agricultural land. With a total number of 238 individuals on 44.33 ha in the secondary forest, there is an average density of 5.37 Jatna's Tarsier per ha and 17 tarsiers per trial plot. On the research plots within the cultivated land, 58 tarsiers were detected on an area of 47.5 ha. This indicates an average density of 1.22 Jatna's Tarsier per ha and 3.87 tarsiers for each trial plot. In the reference area tarsier numbers vary between six to 30 individuals per plot, whereas the numbers in the cultivated land show a lower variance with counts between three and nine individuals.

Inside the agricultural used land 15 cultivation types could be identified. In addition, there are four uncultivated vegetation types, which fall under the term 'cultivation type' for this research. These are bare land, shrub land, forest fragments and river bank vegetation. The only monoculture where tarsiers have been found was cocoa (n = 6) and the only mixtures where tarsier have been observed were a mixture of cocoa and pala nantu (n = 1) and a mixture of cocoa and corn (n = 3). However, most tarsiers were found in the cultivation types which are currently not in agricultural use. Hereby, most tarsiers have been found in forest fragments (n = 21), followed by river bank vegetation (n = 20) and shrub land (n = 6).

Riverside vegetation has been classified into four different categories, ranging from 0 to 3 (Table 1). The parameter contains information about the intensity of riparian vegetation along the river and its horizontal connections.

Table 1. Classes of riverside vegetation in Popayatpo Paguat area.

Class	Explanation
0	No river bank vegetation at all
1	Poor river bank vegetation, not connected
2	Moderate river bank vegetation, partly connected
3	Rampant river bank vegetation, well connected

The conducted generalized linear module (GLM) shows that a significant relation exists for the occurrence of *Tarsius supriatnai* (p-value of 2.76e–15). Same is true when considering the agricultural used plots only (p-value of 0.0019).

The evaluation for forest degradation and conversion was done in accordance with the degree of tree cover loss for each trial plot (Hansen *et al.* 2013). Here, the thresholds of forest degradation (≤90%) and forest conversion (>90%) were consulted according to their definition by the FAO (FAO 2011). The outcome shows that the tarsier occurrence on the plots that have been affected by forest conversion vary significantly from those which are unaffected or experienced forest degradation (p-value of 2e–16).

The area where tarsiers have been detected and where actual cultivation and forest conversion occur included only plantations on which cocoa trees represented the most dominant crop. *Tarsius supriatnai* is able to adapt towards changing habitat conditions, including even forest conversion, to a certain extent. However, it was found that *Tarsius supriatnai* is restricted to areas providing dense vegetation structures like bamboo thickets or rattan/duruh palm stands (Fig. 5). Using this presence - absence - abundance data showed that *Tarsius supriatnai* has a limited indicating function

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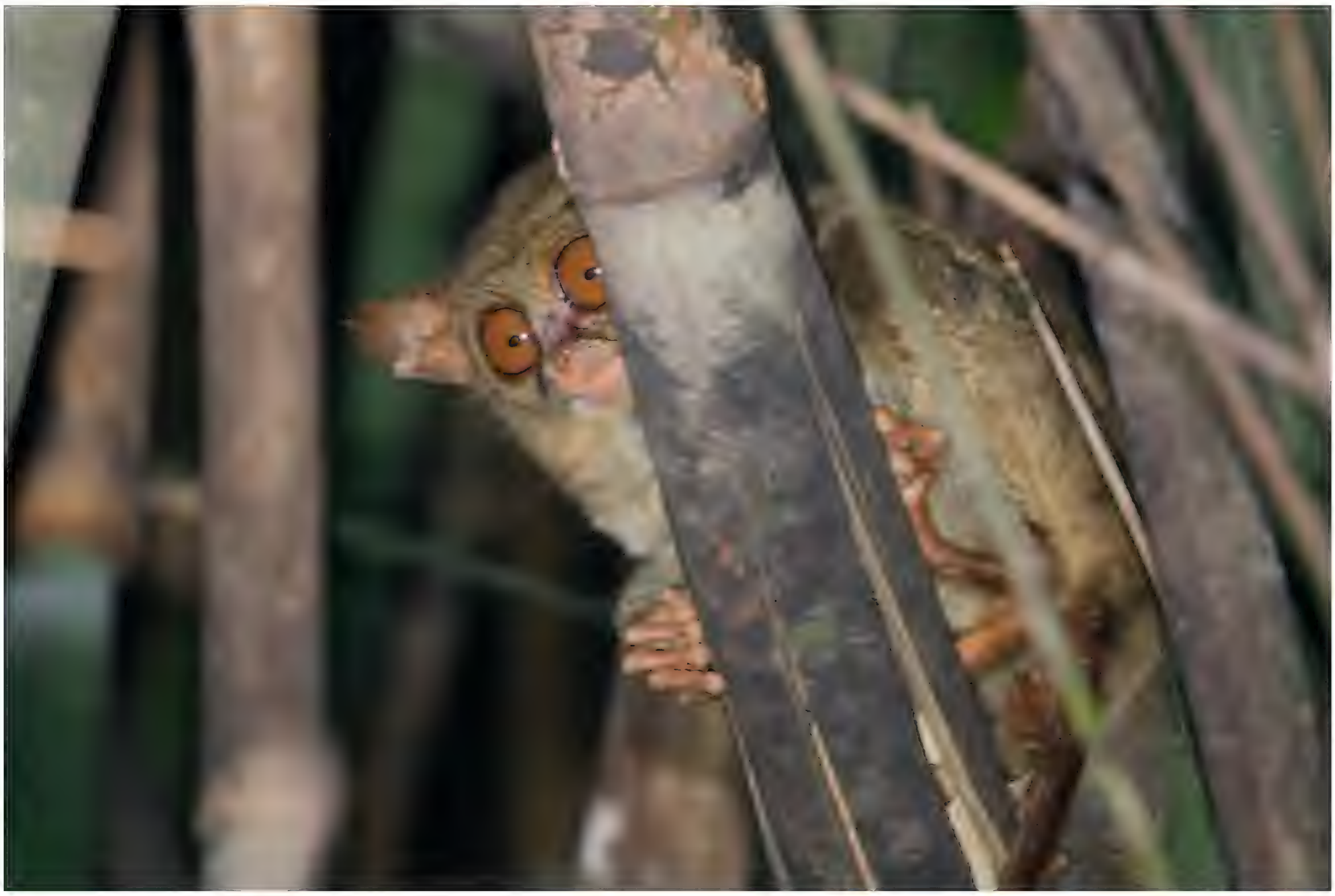

Figure 5. Bamboo as a crucial habitat structure for *Tarsius supriatnai* Shekelle, Groves, Maryanto et Mittermeier 2017 (photograph: Tom Kirschey, 17.i.2020).

to forest degradation or conversion, although population densities decrease significantly with forest conversion. However, *Tarsius supriatnai* could contribute as indicator for (sustainable) agroforest practices including cocoa cultivation that allow well-connected, dense vegetation structures.

Discussion

Already prior to its formal scientific description, *Tarsius supriatnai* was studied and referred to as the "Gorontalo form" of Spectral Tarsier *T. tarsier* (MacKinnon & MacKinnon 1980; Gursky *et al.* 2008) or the "Libuo form" (Shekelle *et al.* 1997; Shekelle 2003; 2008). The terra typica of *Tarsius supriatnai* is Sulawesi, Nantu Forest Reserve, adjoining Popayato Paguat landscape in the Northeast (Shekelle *et al.* 2017). Its characteristic duet call was described as a ~2 to 5-note female phrase accompanied by male calls – a distinct character different from other representatives of the genus (Fig. 6). Population ecology considered similar as in *Tarsius spectrumgurskyae* (e.g., Gursky 2007). Some aspects like site fidelity may be similar in other *Tarsius* Storr, 1780 species, but our investigations allow only preliminary conclusions. Gursky (2007) reported 33 sleeping trees within an area of 100 hectares in Tangkoko Dua Saudara Nature Reserve, North Sulawesi. Twenty trees were still used by *Tarsius spectrumgurskyae* five years later, indicating suitable microhabitats in a dynamic landscape are traditionally used by tarsiers over long time periods.

Our results demonstrate no significant differences between unaffected and degraded plots. The density of riparian vegetation showed a significant relation towards the occurrence of *Tarsius supriatnai*, while the presence of closed tree canopy across the river banks did not correlate with projected population numbers. Out of the 19 identified habitat conversion types, tarsiers were detected in only six of those, whereas the three types showing the highest tarsier occurrence consisted of remnants of natural vegetation.

The results of the present study also demonstrated that the population densities of *Tarsius supriatnai* in the agriculturally used land differ significantly from those inside the secondary rainforest. With a value of 5.37 individuals per ha within the rainforest, the population density is 4.4 times higher as inside the cultivated/converted land

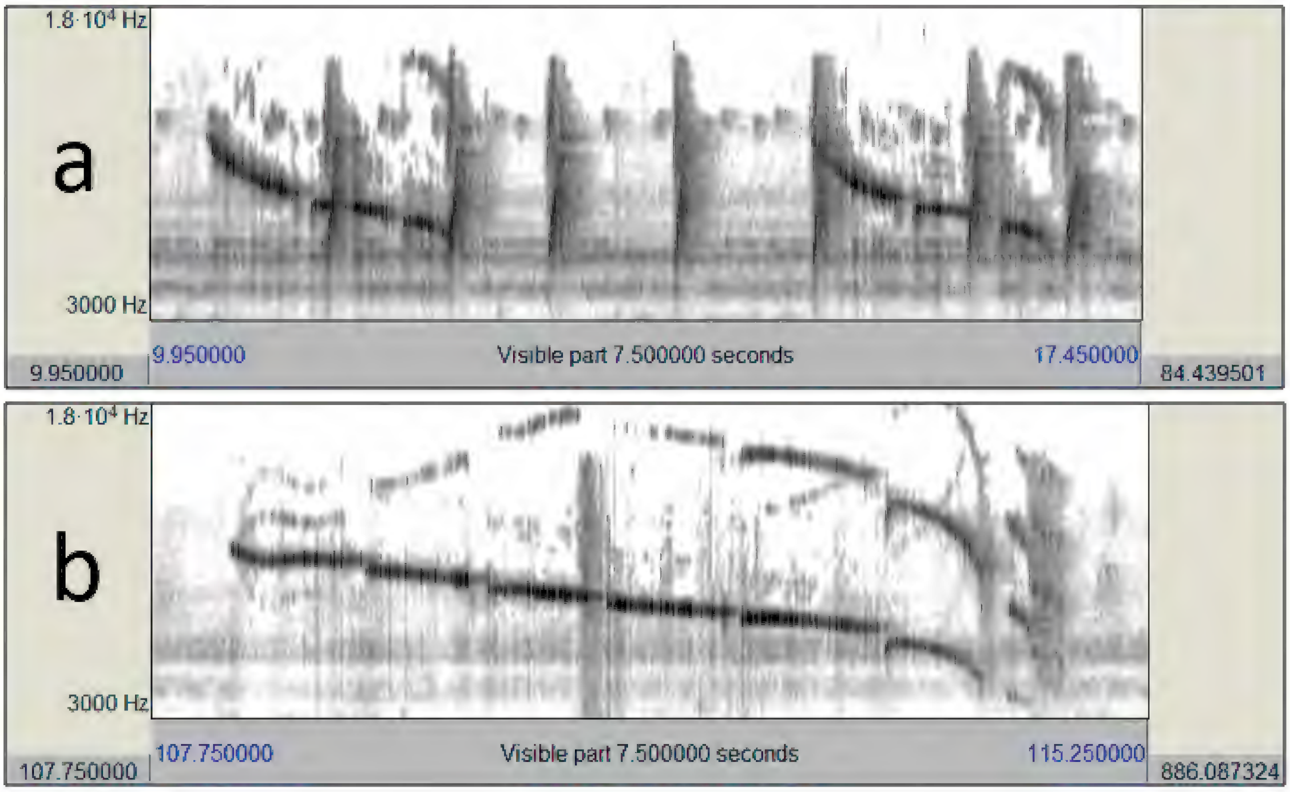

Figure 6. *Tarsius supriatnai* Shekelle, Groves, Maryanto et Mittermeier 2017 spectrograms (created with Praat version 6.0.30): A – A typical duet call; B – A separate female call.

(1.22 tarsiers per ha). Compared to other studies on population densities of species belonging to the genus *Tarsius*, this value is comparatively high (Merker 2003; Gursky 2007; Saroyo *et al.* 2017). This may be due to the proximity of open water bodies, which support rich populations of insects, and because home ranges are not used linearly. Slightly disturbed forest, as it is the case in the study area, is the habitat where tarsier densities were expected to be the highest. According to Gursky (2007), the density of *Tarsius spectrumgurskyae* (a species very similar to *T. supriatnai*) in the secondary forest is even more than twice as high, compared to their actual natural habitat, the undisturbed primary forest. This can be explained by increased light incidence in secondary forests, causing shrub layer to develop stronger, and thus amenable sleeping sites to the benefit of tarsier populations. This demonstrates that forest disturbances may promote tarsier densities to a certain degree. Due to the fact that the secondary rainforest provides dense vegetation, as well as a high number of suitable sleeping trees, tarsiers might not have the need to travel far for their nightly forage activities, which would mean that they require smaller home range sizes. This would confirm the observations by Merker (2003) and Merker *et al.* (2005), who found out that *Tarsius dentatus* Miller et Hollister, 1921 adapts its ranging behaviour according to the degree of habitat disturbance.

Analysis of forest disturbances shows that tarsier densities significantly respond to forest conversion but not to forest degradation. The average population density within the area of conversion (1.05 individuals/ha) is significantly smaller than the density of the other groups (5.65 and 4.07 individuals/ha), whereas the unaffected forest land has the highest population density. This stepwise decrease shows similarities with research on *Tarsius dentatus* by Merker (2003), who stated that population densities are lower in more disturbed habitats, and that the tarsiers do not seem to substantially distinguish between unaffected and slightly disturbed habitats. The reason for the comparatively low population density within conversion plots could be that these rarely provide the vegetation structures as required by tarsiers. It follows that the habitat must at least provide some vegetation which can be used for foraging and as sleeping sites. This corresponds well with the research by Leksono *et al.* (1997) and Yustian *et al.* (2008). Moreover, vegetation height might matter as well. High and dense tree stands provide more shade during the day when tarsiers are sleeping and prevent the inner space from overheating. This kind of microclimate could also be a reason for the high population density within the forested land, compared with the agricultural land.

In conclusion, it can be said that forest degradation and also forest conversion do not amount to total habitat loss for this species, but create new habitat types which are changed to an extent that tarsiers occur in significantly lower numbers. This implies that forest conversion does automatically entail habitat degradation for *Tarsius supriatnai*.

Considering the agricultural used land, only in six out of 19 identified types of cultivation tarsiers have been detected at all. Out of these, three of the types do not actually count as cultivated land, while showing the highest numbers of tarsiers. Specifically, secondary rainforest fragments show the highest number of tarsiers (n = 21), followed by river bank vegetation (n = 20) and shrub land (n = 6). The vegetation types under cultivation were a cocoa monoculture (n = 6), a mixture of cocoa and corn (n = 3) and a mixture of cocoa and nutmeg trees (pala nantu) (n = 1). Since it has been observed that all three cultivation types include cocoa as the most dominant crop, this suggests that cocoa is, compared to the other cultivation types within the agricultural land, a crop which *Tarsius supriatnai* does use (Fig. 7). However, there are three more cultivation types which include cocoa but did also not show tarsiers.

Moreover, it is important to stress that compared to the total area of cocoa plantations, the identified number of tarsiers is still relatively low. Additionally, tarsiers have never been observed to actually sleep within these plantations. Whenever tarsiers have been detected in cocoa plantations, a suitable sleeping location was close-by. In these cases, observed sleeping structures were dense thickets inside forest fragments, bamboo bushes, rattan and salak palms. This circumstance confirms the observations by Merker & Yustian (2008) and Leksono *et al*. (1997) on *Tarsius dentatus* and other *Tarsius* spp. showing that a limiting factor for tarsier occurrence is the availability of suitable sleeping sites. It seems that the combination of cocoa trees (monoculture and mixture) and any dense thicket for resting, does provide sufficient habitat conditions for tarsiers to survive. In these cases, the question remains whether tarsiers, even though they can survive in this habitat, are able to reproduce in numbers sufficient for long-term species survival (Fig. 8).

The results demonstrate that particular riverside vegetation features, especially dense structures containing shrubs as well as trees of various heights and widths play a key role in tarsiers' habitat e.g. by provision of sleeping trees. This could also be one reason why the intensity of riverside vegetation correlates significantly with tarsier occurrence for both the totality of plots and those used agriculturally only (Fig. 7). Riverside vegetation is providing sufficient shade and some kind of microclimate. Cooling effects provided by forests due to evapotranspiration and a closed canopy is reduced to a higher extent on agricultural land. This could also be a reason why most tarsiers have been observed within forest fragments, shrubland and dense riverside vegetation.

Concludingly, it can be said that *Tarsius supriatnai* can persist within agricultural land and does use certain cultivation types and discriminate others. The primates were mostly found on uncultivated land, but were also identified on plantations where cocoa is the most dominant crop. All tarsier-occurrence sites share a dense vegetation structure or close proximity to shrub-like vegetation or bamboo thickets. Moreover, the intensity of river bank vegetation seems to be an important factor conditioning tarsier occurrence, as well as left over secondary forest fragments which have been spared from conversion.

Since it was described in 2017, *Tarsius supriatnai* has been evaluated for IUCN Red List very recently (Shekelle 2020) and included in the category "VU Vulnerable". This corresponds with earlier informal assessments proposed by Gursky *et al*. (2008), but not with "DD Data Deficient" as of Supriatna (2019).

With the present study we aim to contribute to extend the knowledge about this elusive species. With an Extent of Occurrence (EOO) of about 11 000 km^2 and a remaining habitat (potential Area of Occupancy, AOO) of less than 5 000 km^2 area limitations are not as prominent as those for *Tarsius sangirensis* Meyer, 1897 (limited to Sangir Island), *T. tumpara* Shekelle, Groves, Merker et Supriatna, 2008 (limited to Siau Island), *T. pelengensis* Sody, 1949 (limited to Peleng), *T. niemitzi* Shekelle, Groves, Maryanto, Mittermeier, Salim et Springer, 2019 (limited to the Togians) or *T. tarsier sensu stricto* (limited to Selayar). Habitat loss due to deforestation is an ongoing threat on Sulawesi, which progresses at an alarming rate (Cannon *et al*. 2007; Supriatna *et al*. 2020). In Taluditi area of North Sulawesi, deforestation rates increased by 8.6% since year 2000 according to Global Forest Watch (2021) (Fig. 9). Human population increased by 22.4% in Gorontalo Province and by 19.4% in Central Sulawesi Province during 2000–2010, indicating an increasing pressure to the ecosystems (Burung Indonesia 2014).

With continuous habitat loss, decline in its

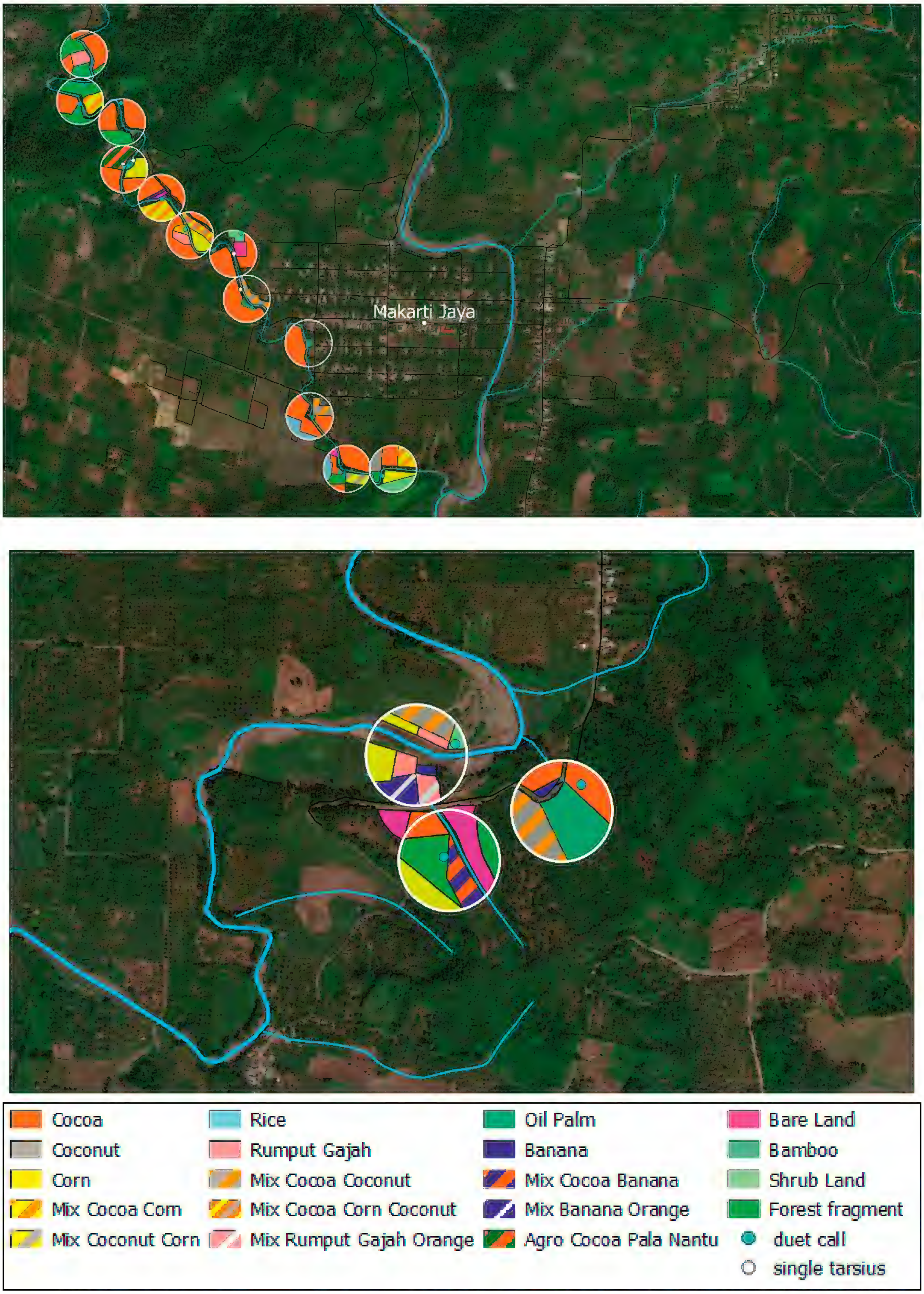

Figure 7. Cultivation types in the agricultural-agroforestry area near Makarti Jaya village, Sulawesi, with tarsier occupation [not to scale].

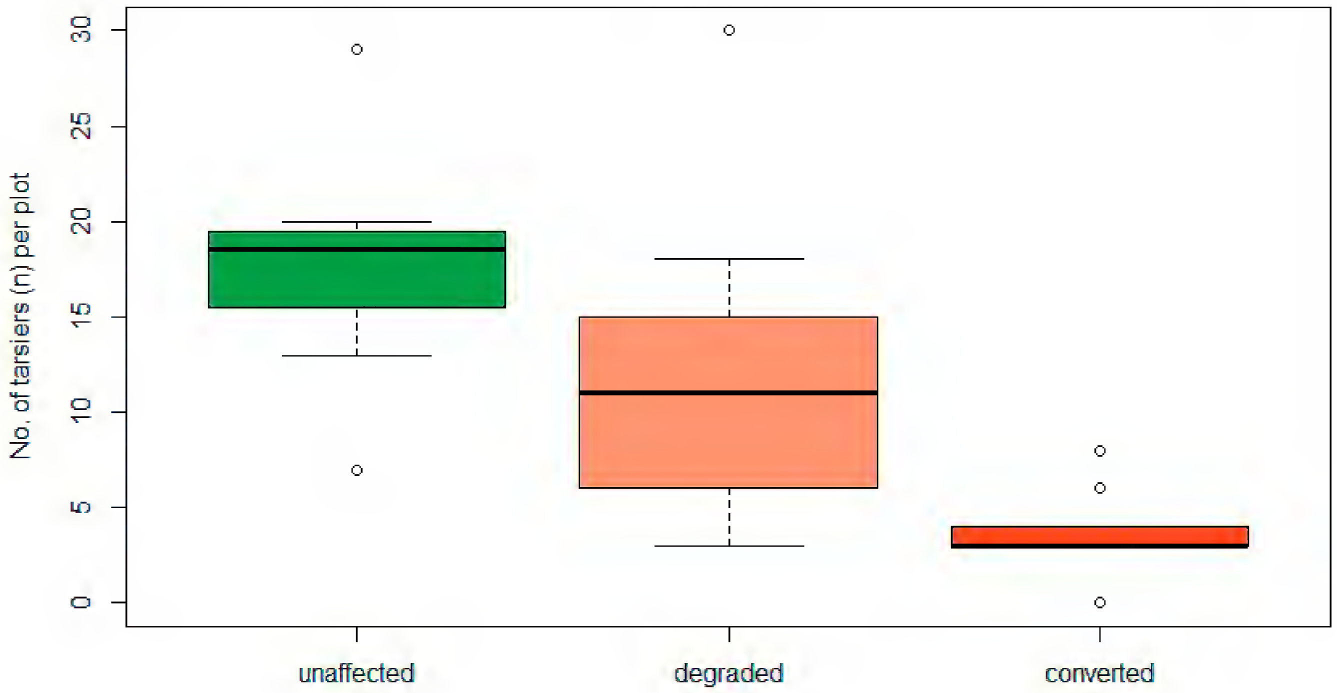

Figure 8. Habitat capacity and tarsier densities in a comparison of 29 trial plots.

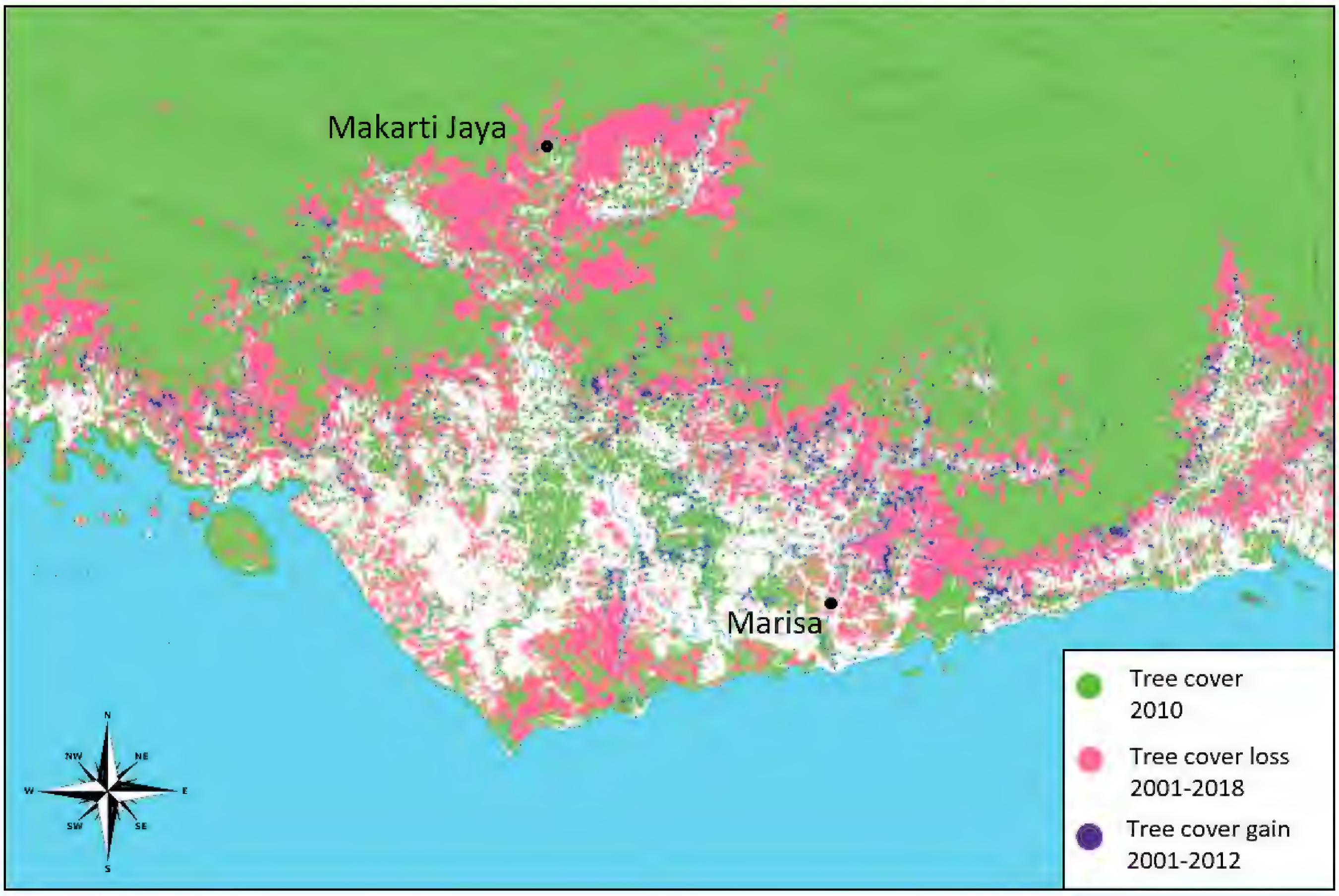

Figure 9. Recent forest degradation and deforestation development in Popayato Pauat landscape in Makarti Jaya area, Sulawesi (source: Global Forest Watch 2021).

extend and quality and other not ceased drivers, we independently support the proposed assessment of *Tarsius supriatnai* as "VU Vulnerable" as of Shekelle (2020) made with accordance with the Guidelines for using the IUCN Red List Categories and Criteria version 14 (2019).

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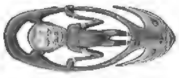

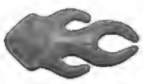

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